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Carbon sequestration and soil properties in forests of Nepal

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ABSTRACT

Forest soils are important for nutrient cycling and development of forest vegetation. The importance of forests of Nepal in carbon storage is globally recognized. In this context, this study reports the findings of systematic analyses of the published journal articles in the past fifty years of Nepal on forest soils of Nepal. It is found that restoration of the degraded forest land is important for maintaining forest soil properties and carbon storage. Socioeconomic factors such as population reduction, promoting off-farm employment and economic incentives are important to reverse forest land degradation.

1. Introduction

Soil carbon sequestration is something that we cannot afford to ignore (Lal, 2004a). Land-use change is also a relatively low-cost and rapidly implementable mean of climate change mitigation (Smith & Scherr, 2002). Soil organic carbon pool can be enhanced by restoration of degraded soils, and conversion to planted fallows, agroforestry, plantations, improved pastures, and mulch farming. There is a vast potential of converting degraded ecosystems and agriculturally marginal soils to agroforestry and forest plantations to restore ecosystems, sequester carbon, and mitigate the greenhouse effect (Lal, 2004b). Land use conversion from cropland to shrubland or wild grassland (i.e. undisturbed land) has also been found better for sequestration of soil organic carbon than tree plantation in the semi-arid loess hilly area loess plateau of China (Chen et al., 2007). Maximizing the productivity of existing agricultural land and applying best management practices to that land would slow the loss of, or in some cases, restore soil carbon. Soil carbon management needs to be considered within a broader framework of sustainable development (Smith, 2008). Reducing deforestation, agro-forestry adoption, reducing soil degradation, and rehabilitating degraded forests are all examples of carbon-sequestering land-use-change practices which can and have been adopted by low-income land users (Tipper, 1997). Forests are the largest carbon stock in terrestrial ecosystems (Bonan, 2008). Carbon sequestration in forest soils has been identified as a potential approach for mitigating the increase of atmospheric CO_2 concentration (Smith et al., 2007; O'Rourke et al., 2015; Conforti et al., 2017), as well as for improving productivity, ecosystem functioning, and sustainability of the Earth System (Liao et al., 2009). Nitrogen plays a crucial role through the interaction with carbon in the ecosystem productivity and carbon sequestration (Knops & Tilman, 2000; Reich et al., 2006; Liu & Greaver, 2010).

Properties that contributed significantly to soil loss variance included percentages of sand, silt, clay, and organic matter; pH, structure and bulk density of plough layer and subsoil; steepness and concavity or convexity of slope; pore space filled by air; residual effects of sod crops; aggregation; parent material; and various interactions of these variables (Wischmeier & Mannering, 1969). Land-use change can have significant impacts on soil conditions, and microbial communities are likely to respond to these changes. Specific changes in edaphic properties, not necessarily land-use type itself, may best predict shifts in microbial community composition across a given landscape (Lauber et al, 2008). The cultivation of the pastures degraded the soil physical properties, leaving soils more susceptible to erosion. This suggests that land disturbances should be strictly avoided in the pastures with a limited soil depth (Celik, 2005).

Nepal can be considered as an interesting choice for analyzing the dynamics of land-use changes, forest and soil degradation and carbon sequestration processes due to its highly fragile ecosystem coupled with one of the most serious problems of forest and soil degradation in the world (Eckholm, 1976; Ives, 1987; Metz, 1991; Upadhyay et al., 2005). The latest data shows that forest area in Nepal represents 44.74% of the total area of the country including forest area covering 40.36% and other Wooded Land 4.38% (DFRS, 2015). In Nepal, we do not have systematized information on the study of soil properties and soil carbon sequestration in forests. So this research was conducted to find out the status of the carbon sequestration and soil properties in forests of Nepal based on peer review indexed articles during the past 50 years (1970-2020). It is expected that the findings will be useful for identifying the current status and research gaps on forest soils of Nepal, and setting priorities for climate change mitigation through forests of Nepal.

2. Materials and Methods

2.1. Search criteria

A search was carried out using keywords 'forest soil Nepal' in Google scholar. Three criteria were used: 1. articles published between 1970 and 2020, 2. keywords only in title of the publications and 3. excluding citations. A total of 29 results were obtained. Two conference papers and one interview document were found in the search results but they were not included in the initial list. One article was repeated. So a list of 25 journal articles was prepared as a result of the initial screening.

2.2. Research synthesis

In the second round of screening, these articles were checked to confirm whether their journals are included in the Scientific Journal Ranking (SJR) list. Only 12 articles were published in the journals included in the SJR list. Out of these articles, one article was a review paper and eleven articles were research papers. A detailed review was conducted of those 11 research articles (Table 1).

Table 1. Themes of selected articles

S.N.	*Theme*	*Number of articles*	*Published year*	*Geographical coverage*
1	Carbon sequestration	5	2005, 2012, 2013, 2019	a. Mardi watershed, mid hill (3), b. Pokhare khola sub-watershed, mid hill (1), c. Kankali community forest, Terai (1)
2	Land use and soil productivity	3	1989, 2001, 2013	a. Eastern Siwaliks (Sub-Himalayan region), the catchment area of the Koshi River (1), b. Chitwan, Terai (1), c. Sindhupalchok district, mid hill (1)
3	Soil properties	3	2003, 2015	a. Kathmandu, mid hill (1), b. Kavrepalanchok district, mid hill (1), c. Terai and mid hill (1)

3. Results and discussion

3.1. Carbon sequestration

Households are likely to use more agriculture, forest and pasture land resources of watershed under the reduced rates of off farm employment opportunities. Such increased uses will speed up more land clearing, soil loss and emissions of carbon with decreased sequestration of carbon. Decreasing population growth contributes to negligible clearance of new land for cultivation, increased biomass, reduced soil loss and reduced extraction of biomass products. This contributes positively to carbon sequestration (Upadhyay et al., 2013). Soil degradation problem as seen in terms of higher amount of soil loss due to erosion processes in the mountain agriculture systems is pervasive in the watershed mainly due to cultivation in high elevation lands which have a steepness of more than 30° (Awasthi, 2004). According to Sitaula et al. (2005), forest degradation, manifested through the decline in forest cover, and the resulting soil erosion and organic carbon losses, is a serious problem caused by a complex coupling of bio-physical, socio-economic and technological factors in the Himalayan watersheds. Reductions in the population growth rate, introduction of improved agricultural technology and increase in the prices of major agricultural crops can help slow down the rates of forest decline, soil erosion and carbon loss or even stabilize or reverse them.

Pradhan et al. (2012) found that soil organic carbon was higher in the upper layer (0– 20cm) in tropical and subtropical forests and rapidly declined below the 20–40cm depth. The amount of soil organic carbon decreased with soil depth. Kafle (2019) found that bulk density and carbon nitrogen ratio (C/N ratio) increases with increase in soil depth in a tropical forest. The soil organic carbon and nitrogen differs significantly across different soil layers up to 1m soil profile depth. Results of this study show evidence of a tropical community forest having a role in storage of soil organic carbon and nitrogen within 1m soil profile depth in Nepal. Forest land oxidized more CH_4 than grazing land, rainfed cultivated land and irrigated cultivated land. Rainfed cultivated land emitted more CO_2 than forest, irrigated cultivated land and grazing land. Temperature explained 46–51% of the variation in CO_2 evolution, whereas it explained only 4–36% of the variation in CH_4 evolution. CH_4 evolution was less dependent on soil temperature than CO_2 evolution (Awasthi et al., 2005).

3.2. Land use and soil productivity

Concentrations of soil organic carbon, total nitrogen and total Phosphorus are much higher in undisturbed tropical *Shorea robusta* Roth (Dipterocarpaceae) forest than landslide-damaged sites. Rates of restoration in soil properties were faster in the early successional stages (1-15 year) than late stages in landslide-damaged sites. Among different soil properties the restoration of soil microbial biomass (carbon and nitrogen) was faster than soil organic carbon and total nitrogen. Higher accumulation of soil microbial biomass and high nitrogen

mineralization rate at late successional stages indicated the re-establishment of enriched soil and restitution of nutrient cycling during the course of ecosystem restoration. N-mineralization (nitrification+ammonification) conducted by soil organisms is generally affected by disturbance due to change in structure and properties of soil and composition of soil organisms (Visser et al., 1983). Nitrification rate generally increases after disturbance and decreases as recovery progresses (Walley et al., 1996). Higher organic matter input through fine roots and litter reflects the re-establishment of vegetation and the formation of nutrient rich soils after disturbance at these sites (Mandal, 1999 in Singh et al., 2001). Soil organisms play a crucial role in increasing the level of soil fertility and accelerating revegetation process through their activities in disturbed soils (Visser et al., 1983).

Burton et al. (1989) found that soil fertility as expressed by organic carbon, total nitrogen, and cation exchange capacity decreased when natural productive forest was converted into agriculture. There was also a decline in soil quality when natural forests became degraded and over-used. Changes in soil quality associated with forest conversion to agriculture were noted in South America (Sanchez, 1979). Previous studies by Allen (1985) in Tanzania found decreases in organic carbon, total nitrogen and exchangeable magnesium; and significant increases in exchangeable calcium and pH due to deforestation. Ghimire et al. (2013) found that continued heavy use of the natural and planted forests of the Middle Mountains, particularly the removal of understory vegetation and leaf litter, and cattle grazing, are considered to be the chief causal factors of the presently observed deterioration in forest hydrological functioning. This situation is typical not only of the Middle Mountain Zone across the Himalaya but is also observed in other densely populated parts of South and South East Asia.

3.3. Soil properties

The higher altitude soil was found to be much more depleted of ^{13}C than the lower altitude soil in a *Pinus roxburghii* Sarg. forest. The decreasing trend of C-isotope (as well as the trend of N-isotope) might be attributed to the lower mineralization rate and net nitrification rate at the higher altitude (Sah & Brumme, 2003). Similar results were obtained by other researchers (Hobbie et al., 2000; Garten, 1993). Baral & Katzensteiner (2015) found that the impact of biomass extraction on soil and foliar nitrogen contents in a community forest was more pronounced than that in a semi-protected natural forest. Soil bulk density was significantly lower and soil C, N, exchangeable K and Mg concentrations were significantly higher in the semi-protected natural forest compared to the community forest. Sah et al. (2003) investigated the possible causal factors of decline of sissoo (*Dalbergia sissoo* Roxb.) in the plain land (locally called as terai) of Nepal. Any correlation was not found between the physical soil factors and the sissoo decline.

The present review showed that the number of research articles published in peer review indexed journals related to forest soils of Nepal is very low (n=11). The coverage of the research sites is specific, that is on watershed, sub watershed and community forest levels. The researches were conducted only on terai and mid hill region of Nepal, no single study was recorded in the mountain region. As the web search using 'forest soil Nepal' as key word revealed only 25 articles published in different indexed and non-indexed journals, in the past 50 years, it is a matter of concern that the research results are not being published and disseminated in scientific literature. The publication of only 11 articles on forest soils of Nepal in peer review indexed journals during this period would really be of paramount importance to the scientific communities and the government. It also raises a concern whether there is sufficient investment in research on forest soils of Nepal that could contribute to better management of forests of Nepal.

4. Conclusion and Recommendation

During the past fifty years, the publication of the research findings about forest soils of Nepal on peer review indexed journals is found to be scarce. The studies show that forest soil is very important in storing the carbon, the storage capacity being variable in different forest types. Carbon sequestration can be enhanced by slowing down the expansion of cultivated land area through a reduction in population growth, maintenance of current rate of off-farm employment and economic incentives. It is concluded that forest soil properties are degraded by the biomass. In addition to the reforestation in degraded landscapes, attention also needs to be given to the on-going management of the reforested areas to balance product usage with watershed functions. Better microbial management practices especially in the initial phase of the ecosystem development are required to accelerate the process of restoration of forest soil properties. The altitude-controlled soil temperature appeared to be an important factor in the reduction of CO_2 evolution at higher altitudes. Forest topsoil contains higher amounts of soil organic carbon, being important to retain organic matter on the forest floor. Involvement of local communities in the management of tropical forest cannot be overlooked in the process of climate change mitigation.

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